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Using optical illusions in the shoulder of a cycle path to affect lateral position

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Abstract

An important factor in single-sided accidents of older cyclists is that they ride off the cycle path onto the verge. Two experiments were performed to assess the feasibility of using virtual 3D objects in the verge to affect the lateral position of bicyclists. In the first experiment, different virtual objects were placed in the shoulder and 1150 passing bicyclists were observed using a fixed camera. The (standard deviation of the) lateral position and speed in four conditions with virtual objects differing in colour, structure, or 3D effect were compared with a control condition in which no virtual objects were applied. In a second experiment, the behaviour of 32 bicyclists aged 50 years or older was measured by mounting two digital action cameras with GPS on the participants' bicycles. The participants cycled a route of approximately 12 km in which several locations were passed, one of these contained 15 virtual objects similar to the ones used in the first experiment placed in the shoulder of the cycle path. Cyclist behaviour was compared with behaviour at a control location consisting of a solitary two-way cycle path with a grass shoulder. Results indicate that the virtual objects in the tested format had little overall effect on cyclists' behaviour. However, bicyclists were positioned closer to the virtual objects and the shoulder when they looked at the objects or when they reported that they saw them while cycling. This suggests that the overall visibility of the object design may have been too conservative.

Keywords

bicycling, illusion, lateral position, virtual objects, safety, behaviour

Highlights

- Effects of different virtual objects in the shoulder on bicyclists' lateral position were evaluated.
- The illusions were not effective in changing cycling behaviour.
- If objects were noticed, cyclists rode closer to them.

1. Introduction

1.1. Cycling in the Netherlands

In the Netherlands cycling is a very popular mode of transportation. Estimations are that 26% of all journeys in the Netherlands are made by bicycle (Ministry of Transport, Public Works, and Water Management, 2008). Cycling can be an effective mode of transportation and an important contributor to physical health and fitness (Oja, et al., 2011) although cycling in traffic is not without risks. In 2012, 59% of all first aid treatments after traffic accidents in the Netherlands involved cyclists (Schepers, 2013).

Several factors influence cycling safety, such as adverse weather conditions, state of the pavement, other road users, defects of bicycles, alcohol or drug use, gender, helmet use, and bicycle use by two occupants (Juhra, et al., 2012; Martínez-Ruiz, et al., 2013; Martínez-Ruiz, et al., 2014). Common types of accidents are falls while getting on or off the bicycle and falls due to potholes or pavement irregularities, kerbstones, or similar (Scheiman, Moghaddas, Björnstig, Bylund, & Saveman, 2010).

1.2. Older cyclists

As our society is ageing, bicycle use by older people is also increasing (Wegman, Zhang, & Dijkstra, 2012). This is a positive development as it contributes to independent mobility, which is an important factor for healthy ageing and quality of life (Fagerström & Borglin, 2010; Törnvall, Marcusson, & Wressle, 2016). However, increasing age is also related to a greater risk for being involved in a serious cycling accident (Martínez-Ruiz, et al., 2014) and for sustaining severe injuries with poor outcome after a crash (Kaplan, Vavatsoulas, & Prato, 2014; Siman-Tov, Jaffe, Peleg, & Israel Trauma Group, 2012). In the Netherlands, 67% of all bicyclist fatalities were among cyclists aged 60 years or older. This is more than twice as much as fatally affected car drivers within the same age group (CBS, 2014).

The increased accident risk for older cyclists can be explained by both cognitive and physical decline (OECD, 2001). Cognitive factors such as a decrease in attention, working memory, and reaction capability can make many traffic situations a more mentally demanding task. Physical factors such as decreased balance, increased muscle stiffness, and bone fragility lead to more severe injuries after a collision or fall. These factors show the need to increase safety for older cyclists, which is currently one of the priorities within the Dutch cycling safety policy (Rijkswaterstaat, 2016).

1.3. Single-sided accidents

Older cyclists in the Netherlands are particularly at risk for single-sided accidents, which are accidents not involving other traffic participants (Schepers & Klein Wolt, 2012). Although minor cycling accidents in the Netherlands are underreported (Schepers & Klein Wolt, 2012; Wegman, Zhang, & Dijkstra, 2012), estimations are that in more than 60% of all cyclist accidents leading to injuries no other traffic participants are involved (Schepers, 2013). In 50% of all single-sided accidents, infrastructural factors are of influence (Schepers & Klein Wolt, 2012; Schepers & den Brinker, 2011; Fabriek, De Waard, & Schepers, 2012) and 33% of these accidents happen on a cycle path (Schepers, 2008).

Westerhuis and De Waard (2016) studied the behaviour of older cyclists in a naturalistic cycling setting and identified behaviour potentially leading to an accident. They found that 20% of the cyclists accidently entered the verge once or more during a week of cycling. Although these events did not lead to any accidents in the observed cases, it is known that in 21% of all single-sided cycling accidents in the Netherlands cyclists end up riding off the road, either hitting a kerbstone or entering the verge (Schepers, 2013). Interacting with a cycling companion (45%), alcohol use (19%), not looking ahead (17%), moving out of the way for another road user or performing an overtaking manoeuvre (13%), or physical problems (12%) are important factors preceding these types of accidents (Schepers, 2008).

1.4. Safety measures

Current Dutch traffic policies are based on the evidence-based “Sustainable Safety” vision, in which several principles are applied to prevent accidents and limit injuries (Wegman, Aarts, & Bax, 2008). The current study is based on the principle of physical forgivingness, meaning that the infrastructure should be designed to prevent accidents or constrain negative outcome (Houtenbos, 2009). Examples of such safety measures are implementing a passable shoulder or reducing the number of objects on a cycle path. As a different form of physical forgivingness, the current study explores the use of optical illusions to influence the position of cyclists preventing them from riding off the road. As, currently, physical objects are mostly used to fence off roads or cycle paths (i.e. posts or bollards), these are objects cyclists can collide with potentially leading to a single-bicycle accident.

1.5. Optical illusions

As optical illusions are visual deceptions they are, in principle, undesirable in any traffic situation as they tend to misinform traffic participants (CREST, 2013). Remarkably, there are indications that they can be used to enhance traffic safety. For example, several studies have shown that the application of transverse delineation on roads can reduce driving speeds in motorised vehicles (Godley, Triggs, & Fildes, 2000; CREST, 2013; Wu, Hu, & Li, 2013). Furthermore, Wu, Hu, and Li (2013) concluded that speed-reducing optical illusions also evoke a tendency in motorcyclists to maintain a more central lateral position, an effect they did not find in car drivers.

A more specific use of optical illusions in the traffic infrastructure is anamorphosis (CREST, 2013; Plankermann, 2013), which is purposefully distorting an image so that it can be seen from different perspectives, at greater distances, or at higher speeds. This paper describes a study in which anamorphic images placed in the cycle path shoulder might be used to affect the behaviour of cyclists.

It was observed during a naturalistic cycling study that cyclists have a tendency to regularly move around objects, such as manhole covers, which may be a threat to balance (Westerhuis & De Waard, 2016). Therefore, it was hypothesised that creating virtual objects in the shoulder of a cycle path influences the lateral position of cyclists by provoking a natural reaction to avoid colliding with this object. As the object can be perceived either consciously or unconsciously through foveal vision or peripheral vision, respectively, lateral distance to these objects (and therefore the shoulder) should be increased. Furthermore, it was hypothesised that cyclists would lower their speed as an anticipatory reaction as they pass the objects.

The virtual objects were placed along the right-hand side of the cycle path so that they would be perceived in the peripheral visual field of passing cyclists and function as a subtle warning signal that the edge of a cycle path needs to be avoided. Furthermore, because the illusions would only simulate height, these measures would automatically be ‘forgiving’ because cyclists simply cannot collide with them as they are flat drawings and not physical objects. Eventually the idea evaluated is that virtual objects could increase distance to potentially dangerous shoulders using two different experimental approaches.

2. Method – Experiment 1

2.1. Virtual objects

Based on anamorphic optical illusions, an image was created which represented a three-dimensional box when viewed from the correct position. As this was a first study, a simple box was chosen and not a threatening image to restrict the chance on potentially intense reactions. To determine the appropriate size and location for the object, a ‘real’ prototype box (12.5 x 12.5 x 28.5 cm) was created first. Subsequently, a virtual version was made by first locating the edges of the real model and drawing them on a two-dimensional surface on the exact locations from which a human spectator saw these. A longitudinal perspective of 3.6 m was used, for functional as well as practical reasons (see figure 1). It was hypothesised that the illusion would have its strongest effects on cyclists who were cycling relatively close to the edge of the cycle path. Therefore, a lateral distance of 50 cm was used for the perspective of the illusion. The virtual object was completed by connecting the edge-points using Adobe Photoshop™. The resulting images and dimensions are displayed in figures 2, 3, and 4. The same virtual objects were used for both experiments, which were approved by the Ethical Committee of the Department of Psychology of the University of Groningen.

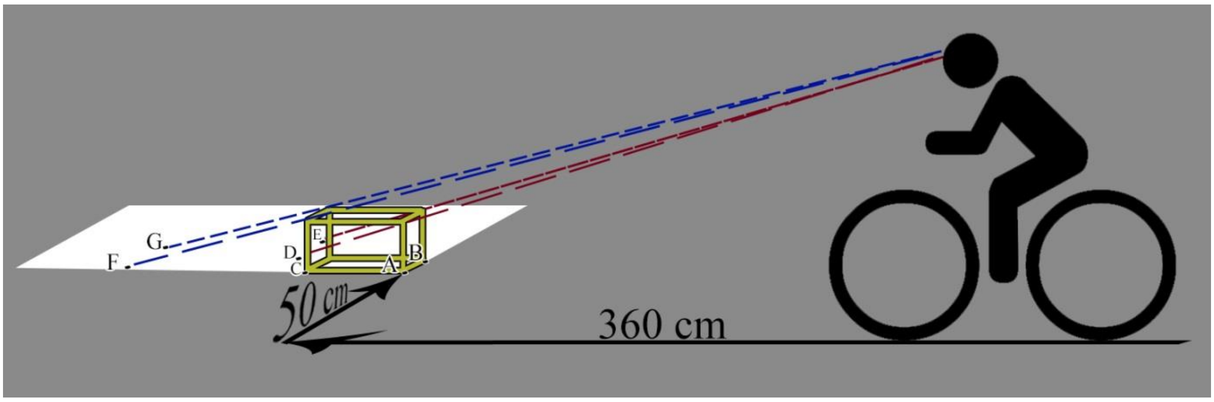

Figure 1: An illustration of the way the virtual image was constructed from the perspective of a human spectator.

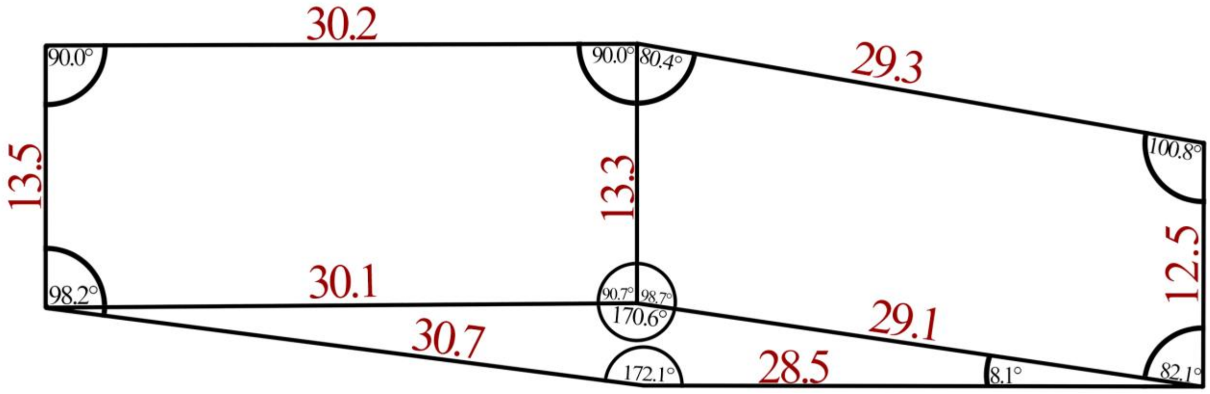

Figure 2: Top view of the resulting lay-out of the virtual image. The dimensions are in centimetres.

2.2. Experiment 1: Fixed perspective

Cyclists were observed on a crowded bicycle path on a location close to the main public transport station in the city of Groningen. On this location, the behaviour of passing cyclists was observed from a fixed perspective using a video camera and different versions of the virtual objects were placed on the right-hand side of the two-way cycle path (figure 3). The virtual objects were printed and glued to a thin piece of wood so that they could be placed and removed quickly. The objects were placed 0.2 m in the verge, therefore the illusion would have its strongest effects when a cyclist would cycle 0.3 m from the edge of the cycle path. Only cyclists who passed the illusions on their right were included.

Figure 3: A bicyclist's view of the experimental location in the city of Groningen.

2.3. Experimental conditions

In the first condition, a grey 3D illusion was placed next to the cycle path. In the second condition, the grey 3D illusion had a stone structure print added to it. The third condition had a red coloured virtual 3D object with white horizontal striping similar to commonly used cycling bollards in the Netherlands. The fourth condition consisted of a two-dimensional object, which had the same total surface area as the 3D versions, yet entirely printed in black. The fifth and last condition was a control condition in which no objects were placed along the cycle path. An overview of the different (virtual) objects is presented in figure 4. During each condition, three identical objects were placed with 3.6 m of space between them. During five days all conditions were presented to passing bicyclists for 30 minutes in a randomized order, resulting in a total observation time of 150 minutes per condition.

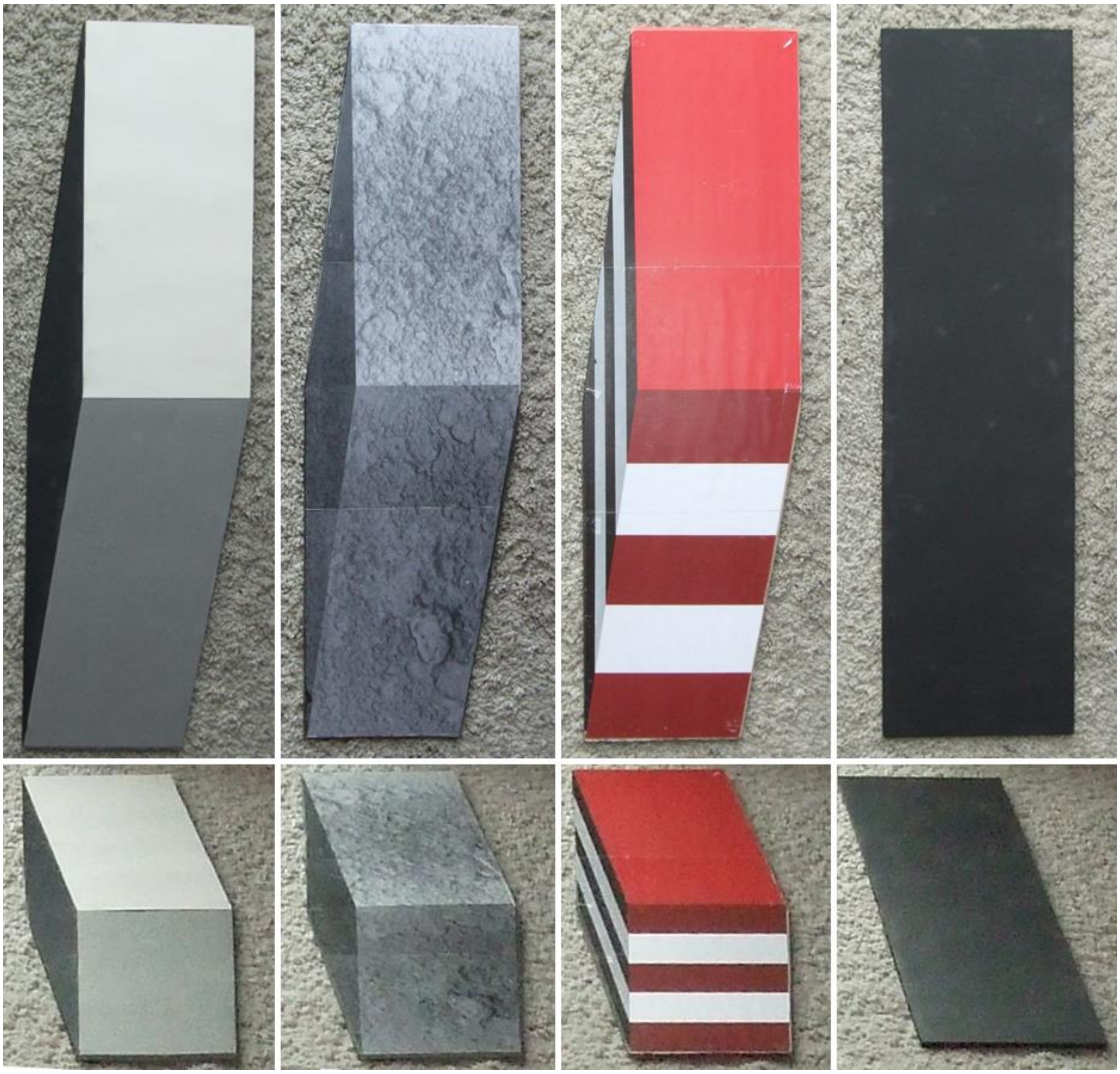

Figure 4: An overview of the different types of optical illusions used during Experiment 1. From left to right: grey virtual 3D object, grey virtual 3D object with structure, red coloured virtual 3D object with white striping, 2D black object. During the control condition no virtual objects were placed along the cycle path.

2.4. Material

Cyclist's behaviour was recorded using a JVC Everio digital camcorder fixed to a lamppost close to the cycle path. A total of 12½ h of video footage was collected between the 3rd and 12th of June 2014, all in dry weather conditions.

2.5. Video analysis

The video data were analysed using the software programme Kinovea™ for Windows™. A perspective grid was placed over the cycle path using pre-recorded positions marked by the researchers (see figure 5). The dimensions of the grid were adjusted to represent the real size of the measurement area (7.2 x 3.0 m). Subsequently, the position of the cyclist's front wheel along the grid was semi-automatically tracked using the 'track path' tool. The tracking was initiated when the cyclist's front wheel entered the grid and was ended as soon as the front wheel left the grid. Bicyclists who were accompanied or bicyclists who followed another bicyclist at approximately 7 m or less (the length of the grid) were excluded from the analysis.

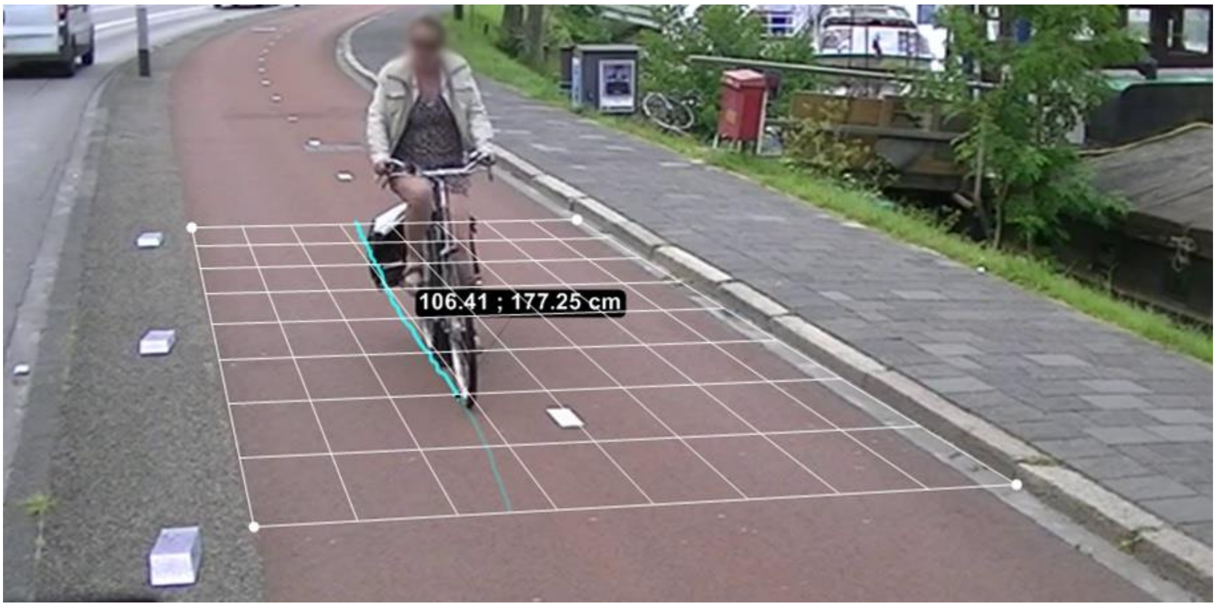

Figure 5: An illustration of the cyclist position measurement process. Using Kinovea™, a perspective grid was placed at the experimental location and calibrated reflecting the length and width of the cycle path measurement area (7.2 x 3.0 m). Along the grid, the position of the front wheel was semi-automatically tracked and lateral position (horizontal position) and speed were sampled.

2.6. Statistical Analysis

Effects of the virtual object conditions on cyclist lateral position, swerving behaviour (SD of the Lateral Position, SDLP) and speed were analysed using a multivariate analysis of variance (MANOVA), as the data were normally distributed and based on large sample sizes. SDLP data were logarithmically distributed, therefore its values were first transformed to a normal distribution before performing the analysis. Statistical analyses were performed using IBM SPSS Statistics™ 22 for Windows™ and an α-value of 0.05 was applied to assess statistical significance. When applying multiple comparisons, the p-value was Bonferroni corrected. Lastly, eta squared (η^2) values were computed to determine effect sizes of multivariate comparisons, of which values of $\eta^2 = 0.0099$ were interpreted as small effect sizes, $\eta^2 = 0.0588$ as medium effect sizes and $\eta^2 = 1.379$ as large effect sizes (Cohen, 1988). For pairwise comparisons, Cohen's d was calculated as the measure of effect sizes, of which d < 0.20 corresponds to negligible effects, d = 0.20 represents a small effect, d = 0.50 a medium effect and d = 0.80 corresponds to a large effect (Cohen, 1988).

3. Results – Experiment 1

3.1. Experiment 1

During Experiment 1, a total of 744 min of video data recorded from the fixed camera perspective were analysed, and a total of 1150 cyclists were scored. Fifty-five percent of the cyclists were men and at least 205 cyclists were scored per condition. For an overview of all scored participant characteristics, see table 1.

Table 1: Scored participant data per condition.

Condition	N	Male (%)	Without oncoming bicyclist (%)	Looking at one object at least (%)	Total video time analysed
Control	228	57.0	78.5	n/a	153min
2-Dimensional	271	54.2	78.6	18.5	155min
3D: No Structure	205	55.6	79.5	36.6	140 min
3D: Structure	224	55.8	80.8	43.3	148 min
3D: Red Coloured	222	54.1	79.3	44.1	148 min
Total	1150	55.3	79.3	27.8	744 min

During data processing it was observed that, by judging upon their head movements, several bicyclists were looking at the objects, an indication that they had noticed these while cycling (table 1). Furthermore, as the experiment was performed along a bidirectional cycle path, it was also noted that 21% of all participants passed the experimental conditions while one or more oncoming cyclists were present on the opposing lane. For these reasons, it was also analysed whether these factors exerted any effects on the lateral position, SDLP or speed of the participants by including these variables in the analysis.

The results for the MANOVA are depicted in table 2. Small significant effects were found for the virtual object conditions and very small effect sizes were found for looking at the objects, although these effects were marginally significant. Medium and significant effects of oncoming cyclists were also found. All remaining interaction effects were non-significant and resulted in negligible effect sizes (table 2).

Table 2: Multivariate test results for the effects of illusion conditions, looking and oncoming cyclists on speed, lateral position, or SDLP.

Effect	Value	F	df	p	η^2
Condition	0.03	2.49	12, 3396	0.003*	0.009
Looking	0.01	2.58	3, 1130	0.052	0.007
Oncoming	0.08	31.63	3, 1130	<0.001*	0.077
Condition x Looking	0.01	0.99	9, 3396	0.45	0.003
Condition x Oncoming	0.01	1.10	12, 3396	0.36	0.004
Looking x Oncoming	<0.001	0.07	3, 1130	0.98	<0.001
Condition x Looking x Oncoming	0.01	1.28	9, 3396	0.24	0.003
* = significant at p < 0.05					

3.2. Illusion conditions

To explore the effects of the different forms of 3D objects, the mean lateral position per condition is depicted in figure 6. The analyses showed negligible non-significant effects of the conditions on lateral position ($F(4, 1132) = 1.69$, $p = 0.15$, $\eta^2 = 0.006$) and SDLP ($F(4, 1132) < 1$, $p = 0.86$, $\eta^2 = 0.001$). However, a small significant effect of condition on cyclist speed was found ($F(4, 1132) = 5.33$, $p < 0.001$, $\eta^2 = 0.018$, figure 7). Additional Bonferroni corrected pairwise comparisons were performed to determine the effects of each individual condition on cycling speed, revealing negligible and non-significant results for the *3D: No Structure* and *2-Dimensional* conditions (see table 3). However, small effects were found for the *3D: Structure* and *3D: Red Coloured* conditions, of which only the latter reached significance (table 3). This finding indicates that cyclists rode at a higher speed during the red coloured condition.

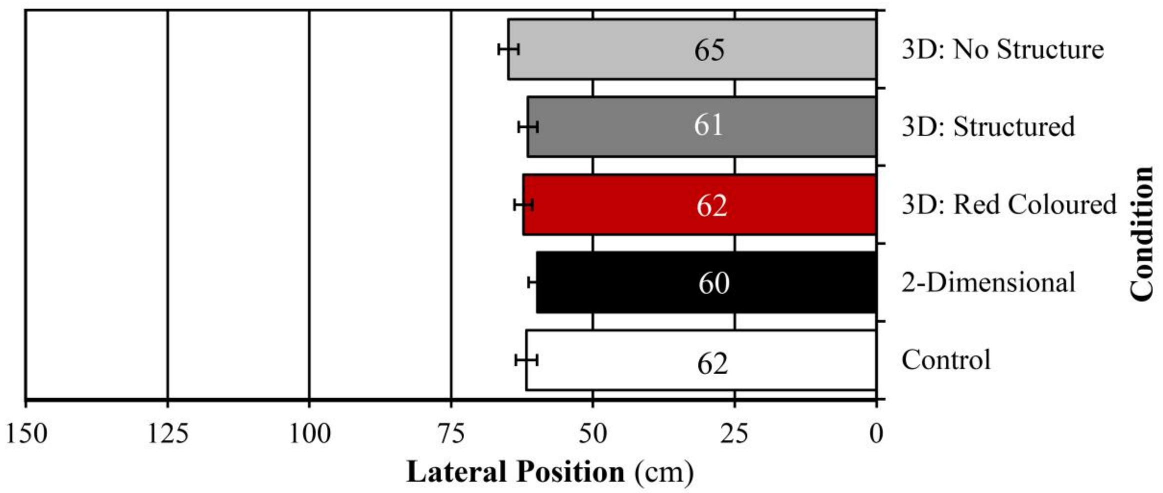

Figure 6: The mean lateral position (in centimetres) of bicyclists passing the experimental and control conditions. The error bars represent the Standard Error of the Mean (SE).

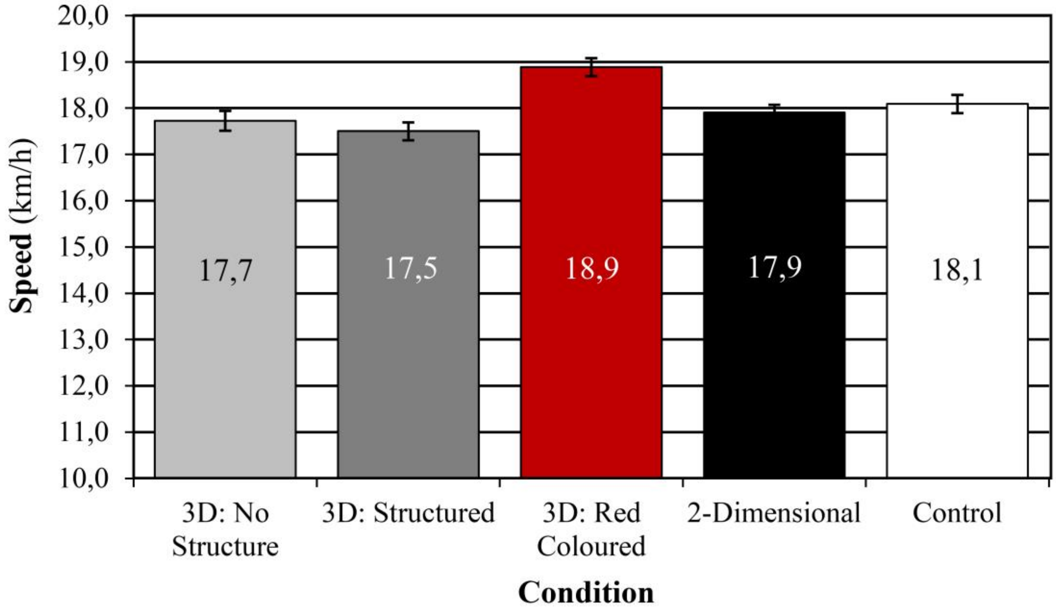

Figure 7: The mean cycling speed (in kilometres per hour) of bicyclists passing the experimental and control conditions. The error bars represent the Standard Error of the Mean (SE).

Table 3: Bonferroni corrected post hoc tests for the effects of condition on cycling speed.

Condition (I)	Condition (J)	Mean Difference (I-J)	SE	p*	d
3D: No Structure	Control	-0.36	0.28	1.00	0.121
3D: Structure	Control	-0.59	0.27	0.30	0.202
3D: Red Coloured	Control	0.80	0.27	0.04**	0.272
2-Dimensional	Control	-0.19	0.26	1.00	0.066

* = Bonferroni adjusted p-value for multiple comparisons
** = significant at $p < 0.05$

3.3. Looking at the objects

As displayed in figure 8, additional analyses on looking behaviour showed very small significant effects on lateral position as cyclists looking at an object were positioned closer to the edge of the cycle path compared to cyclists who were not looking at an object ($F(1, 1132) = 7.65$, $p = 0.006$, $\eta^2 = 0.007$). Further comparisons per condition resulted in negligible and non-significant effects for the *3D: Structure* and *3D: Red Coloured* conditions. Small effects for cyclists looking at the *3D: No Structure* and *2-Dimensional* conditions were found, however, only the effect for the *2-Dimensional* object condition was significant, indicating that the cyclists who were looking at the 2-Dimensional objects rode closer to the edge of the cycle path than cyclists who were not looking at these objects (see table 4).

Table 4: Bonferroni corrected test results for the effects of cyclists who looked at the objects versus cyclists who did not look at the objects on lateral position.

Condition	Mean Square	df	F	p*	η^2
3D: No Structure	3027.4	1, 203	4.997	0.104	0.024
3D: Structure	268.3	1, 222	0.438	1.00	0.002
3D: Red Coloured	304.9	1, 220	0.553	1.00	0.003
2-Dimensional	5234.6	1, 269	8.180	0.02**	0.030

* = Bonferroni adjusted p-value for multiple comparisons
** = significant at p < 0.05

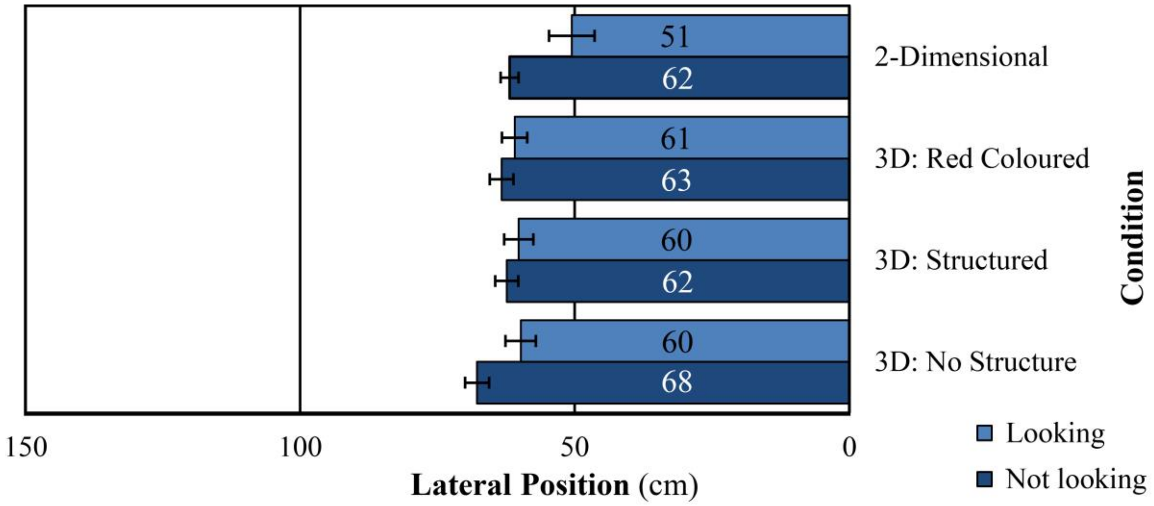

Figure 8: The mean lateral position (in centimetres) of bicyclists either looking or not looking at the virtual objects while passing the experimental conditions. The error bars represent the Standard Error of the Mean (SE).

3.4. Presence of oncoming cyclists

Overall, a medium and significant effect for the presence of oncoming cyclists on lateral position was found, as cyclists who were cycling without any oncoming cyclists maintained a greater distance to the shoulder (M = 66 cm, SD = 25 cm) compared to cyclists who met oncoming cyclists (M = 46 cm, SD = 19 cm), F (1, 1132) = 92.22, $p < 0.001$, $\eta^2 = 0.075$ (see figure 9). However, the interaction term *Condition x Oncoming* was not significant and resulted in negligible effect sizes (see table 2).

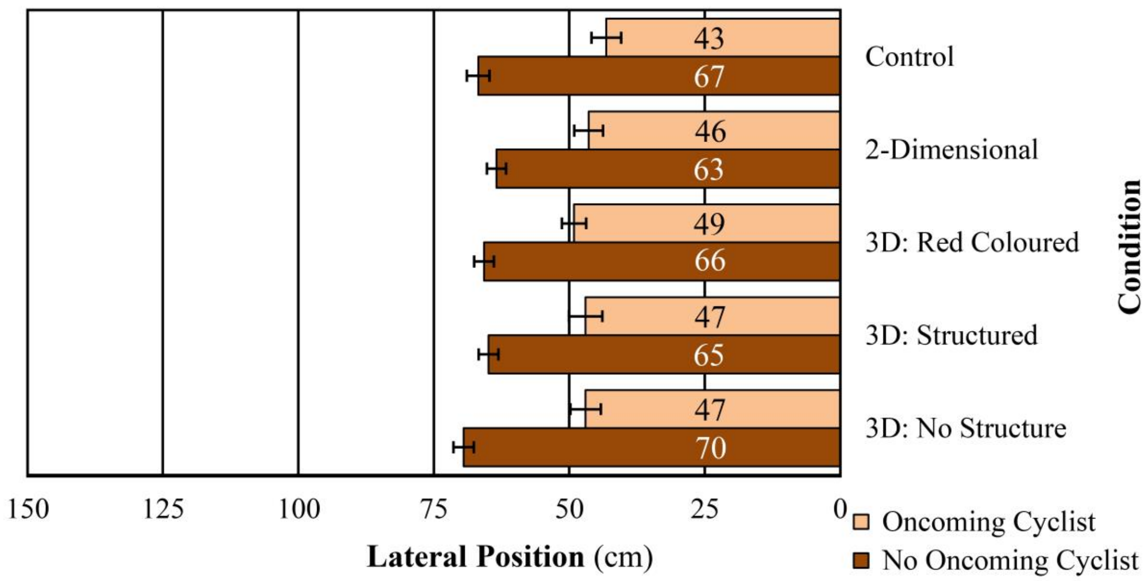

Figure 9: The mean lateral position (in centimetres) of bicyclists either being in the presence or absence of one or more oncoming cyclists while passing the experimental and control conditions. The error bars represent the Standard Error of the Mean (SE).

4. Method – Experiment 2

The second study was an experimental study with participants and was performed on a cycle path located near a small village in the Netherlands. This experiment was performed as part of the 'forgiving cycle path' project (Westerhuis & De Waard, 2014) in which the effects of several measures in the shoulder of a cycle path were assessed. During this experiment, participants aged 50 years and above were asked to cycle a route of 12 km and their behaviour was observed using mobile cameras mounted on their bicycles. On the experimental location, 15 virtual objects were painted on pavement tiles and placed along the right-hand side of a cycle path. Objective as well as subjective data were gathered from bicyclists using either a European city bicycle or an electric bicycle (pedelec). In this paper, the effects of the virtual objects will be presented only. The participants received 15 euros for their participation in this study.

4.1. Participants

A total of 32 participants aged 50 years and above participated in the second study, of which 18 were male. A European city bicycle was used by 17 participants and 15 participants used an electric bicycle. Participants were recruited locally by placing ads on a local TV station and in local supermarkets, as well as via word of mouth. The mean age of the participants was 68.3 years (SD: 9 years). Bicyclists using an electric bicycle were slightly older (M = 70.2 years, SD = 9.8 years) than bicyclists using a European city bicycle (M = 66.5 years, SD = 8.0 years). On average, the participants made six bicycle trips per week, corresponding to a total weekly cycling distance of 46 km. On an overall level, all participants were healthy although 47% experienced physical and 28% reported mental complaints to some degree (i.e. overall stiffness of joints, painful knees, feeling uncomfortable in busy or unclear traffic situations, reduced reaction speed, for example). Nearly all participants used their own bicycles, one made use of the possibility to borrow a bicycle.

4.2. Location

Approximately one kilometre after the start of the cycling route, 15 virtual objects were placed in the right-hand cycle path shoulder (see figure 10, right-hand photo). These virtual objects were identical to the grey objects used in Experiment 1. On this location, the objects were painted on pavement tiles of 0.4 x 0.6 m, as displayed in figure 11. Every pavement tile containing an illusion was followed by five non-painted pavement tiles, resulting in a repeating pattern of one virtual object per 3.6 m. In accordance with the first study, the objects had been positioned 0.2 m to the right of cycle path edge, again so that the illusion would have its strongest effects when a bicyclist was positioned 0.3 m from the edge of the cycle path. The objects were placed along a cycle path section of 50 m that was 2.3 m wide. Participants also passed a control location shortly after they left the village. This control location was also a solitary two-way cycle path of 2.3 m wide although this path was paved in asphalt and had a grass shoulder (figure 10, left photo).

Figure 10: The control condition (left photo) and the experimental condition (right photo).

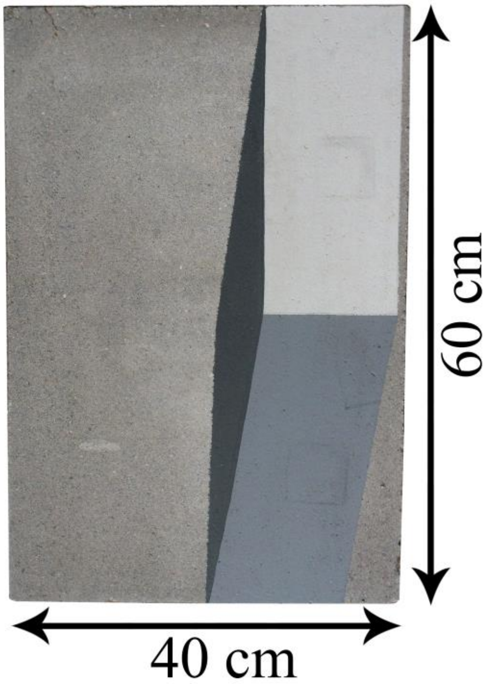

Figure 11: A top down view of the pavement tile containing the virtual object.

4.3. Questionnaire and interview

The participants were asked to fill in a questionnaire which contained sixteen items concerning general, demographic, and cycling information, such as the type(s) of bicycle(s) used and whether the participants used medication or not. This questionnaire was sent to the participants in a letter beforehand as part of a package. This package also contained instructions for the study and the starting location.

Immediately after each participant's bicycle ride was completed, an interview was conducted. During this interview, subjective data concerning the virtual object visibility and the bicyclist's experiences were collected by asking participants thirty questions about what they had seen during the route, how they interpreted what they had seen, and what their opinion was concerning bicyclist safety, distraction, and potential risk. Also, the participants were asked what their thoughts were while they were cycling along the virtual objects. Most questions were open-ended questions (17) to collect unbiased and spontaneous answers and the questionnaire also contained 13 closed-ended questions. Nine questions were about the virtual objects. Furthermore, participants could report their experiences using the video recording of their own journey which was presented on a 15” laptop screen during the interview. These videos were displayed after the participants had answered the open questions concerning what they remembered about their bicycle trip, again to make sure that the first answers collected were unbiased and spontaneous, and also as a measure of object visibility.

4.4. Video recordings

Cycling behaviour was collected using video recordings made with two Contour+2™ digital action cameras with GPS mounted on the front of the participants’ bicycles. One camera was directed forward to the cycle path ahead for a situational overview and the other was directed downward for increased accuracy in lateral position measurements. The videos were recorded using a resolution of 1280x720 pixels at a frame rate of 30 frames per second.

4.4.1. Observable behavioural measures

Cycling behaviour was assessed by measuring speed (km/h), the lateral position (in centimetres), and by calculating SD of the Lateral Position (SDLP). A total of 30 lateral position samples per condition were scored by measuring the distance of the front wheel to the edge of the cycle path using a digital ruler (JRuler Pro™ 3.1 for Windows™). Because the cameras were equipped with 170° widescreen lenses, a measurement aiding tool was filmed before each bicycle trip to allow for correct measurement of lateral position.

4.4.2. Statistical Analysis

Effects for the virtual objects on cycling speed, lateral position, and SDLP were analysed by comparing the virtual objects condition with the control condition. As all dependant variables were not normally distributed, non-parametric Wilcoxon Signed Rank Tests were performed while applying an α-value of 0.05 to determine statistical significance. Effects of bicycle type were analysed using Bonferroni corrected multiple Mann-Whitney U Tests to control for the problems of multiple testing. Effect sizes were calculated for non-parametric data using the r statistic: an r value of 0.5 corresponds to a large effect, a value of 0.3 represents a medium effect and 0.1 represents a small effect size (Fritz & Morris, 2012). All statistical analyses were performed using IBM SPSS Statistics 22™ for Windows™.

5. Results – Experiment 2

5.1. Behavioural measurements

Because the virtual objects could only be placed on one side of the cycle path they were only passed once, on the way to the turning point. Behaviour on this location is compared with a control location during the same phase of the trip. To determine the effects of the virtual objects on lateral position, SDLP, and speed of bicyclists, non-parametric Wilcoxon Signed Ranks tests were performed in which condition was used as within-subjects factor. As displayed in figure 12 and table 5, the virtual objects revealed negligible and non-significant effects on lateral position and SDLP. However, there was a small effect found of condition on cycling speed which did not reach significance. Lastly, small non-significant effects were found of bicycle type.

Table 5: Multivariate test results for the effects of the virtual objects condition versus the control condition on cyclist lateral position, speed, and SDLP.

Variable	Rank	N	Mean Rank	Sum of Ranks	Z	p	*r*
Lateral position	Negative Ranks	17	16.18	275.0	-.206	0.84	0.04
	Positive Ranks	15	16.87	253.0			
Speed	Negative Ranks	12	15.79	189.5	-1.393	0.16	0.25
	Positive Ranks	20	16.93	338.5			
SDLP	Negative Ranks	17	15.06	256.0	-0.150	0.88	0.03
	Positive Ranks	15	18.13	272.0			

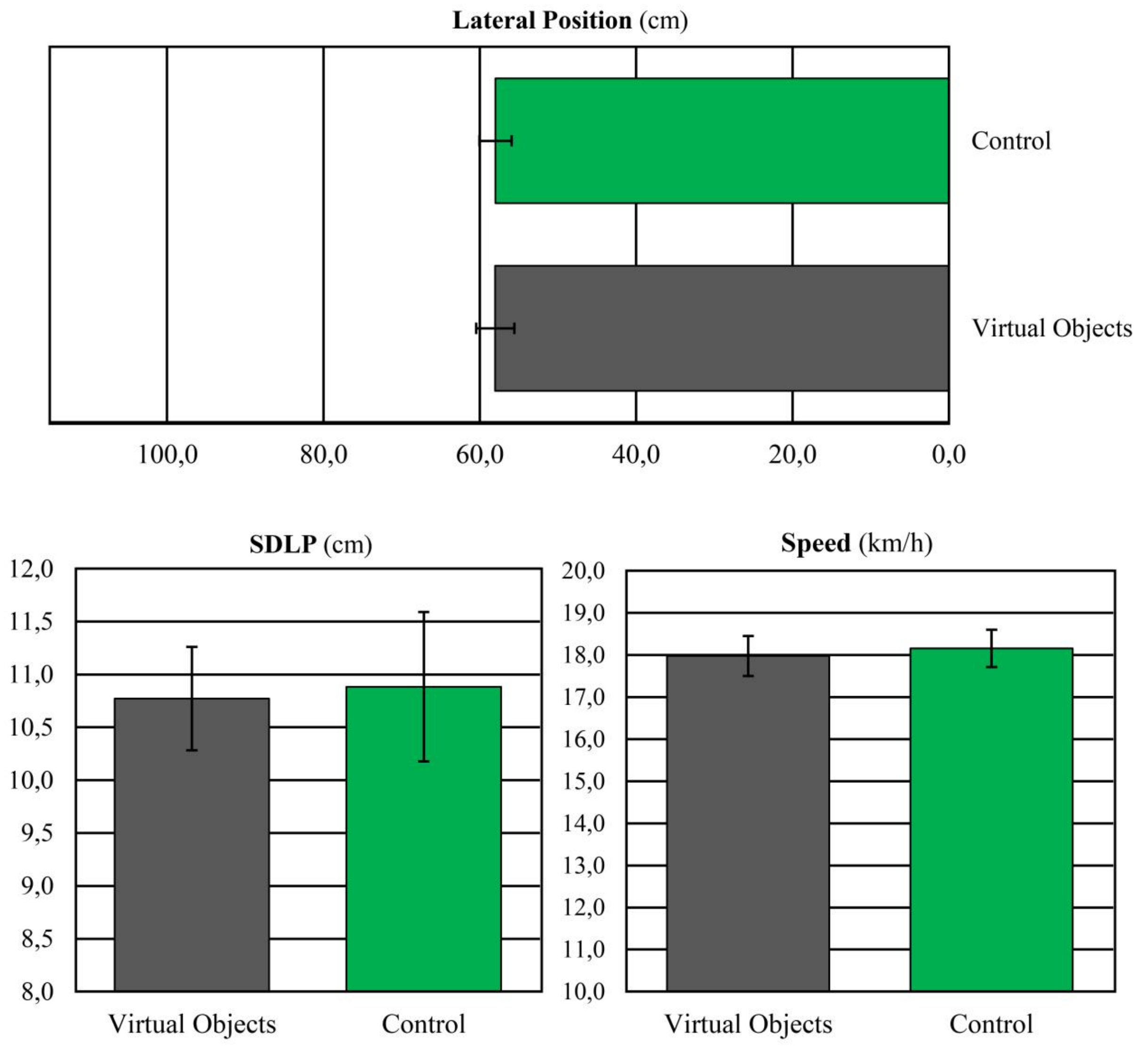

Figure 12: An overview of the measurements on the experimental and the control location: lateral position (top graph), SDLP (lower left graph), and speed (lower right graph). The error bars represent the Standard Error of the Mean (SE).

5.2. Visibility

After each trip, the participants were first asked about their experiences during their bicycle ride along the route. Without actually mentioning the virtual objects, the participants were asked whether they had noticed any 'adjustments' along the route. The experimental location was described as "*the part of the route in an urban area in which the cycle path surface was made of pavement tiles. There was also a fence to the right of this cycle path.*" Based on these instructions, it was assessed whether the participants mentioned the objects spontaneously and if so, how they described these. After these instructions, 9% of the participants mentioned the virtual objects instantly. For the remaining participants whom could not remember anything, a picture of the location and the objects was shown after which an additional 13% said they did remember the objects. This resulted in an overall percentage of 22% (n = 7) of participants who had seen the virtual objects. Using these data, non-parametric Mann-Whitney U tests were performed to assess differences on the behavioural measures between these groups. Although based on different group sizes (n = 7 vs. n = 25), analyses indicated medium and significant effects of looking on lateral position and SDLP, as bicyclists who had seen the virtual objects rode 12.5 cm closer to the shoulder of the cycle path ($U (30) = 41.0$, $Z = -2.120$, $p = 0.034$, $r = 0.37$) and also swerved more ($U (30) = 34.0$, $Z = -2.439$, $p = 0.015$, $r = 0.43$) compared to bicyclists who had not seen the objects. A small effect on speed was also found although this was not significant ($U (30) = 61.0$, $Z = -1.208$, $p = 0.23$, $r = 0.21$). On the control location only small and non-significant differences were found on all three measures.

5.3. Subjective measures

During the interview, bicyclists were asked about their opinion concerning the virtual objects in the shoulder of the cycle path. First, when mentioning the location but not explicitly the objects the answers given were fairly diverse, ranging from “the illusions were not conspicuous”, ”I saw them and thought they were real” and “it suggests that you cannot cycle there” to “looked like a concrete stumble stone”. Moreover, several non-relevant answers were given, such as: “I saw a former colleague” and “I saw white delineation”. After showing the participants a photo of the location with the objects and their own recorded bicycle trip, they were asked what they thought about the measure in general. Of the most commonly given reactions, the majority was mainly neutral or slightly negative as many mentioned that they did not see any benefit for bicyclists (33%). They thought the virtual objects were inconspicuous (22%), dangerous or scary (19%), they thought bicyclists could fall over them (11%), or 15% gave a neutral reaction or had no opinion about the measure.

6. Discussion

In this study the effects of anamorphic optical illusions on the lateral position and course of cyclists were assessed by performing two observational studies. In the first study, data were collected from a fixed camera perspective and in the second study data were obtained from the bicyclist’s perspective. During the first study 1150 passing bicyclists were observed, scored, and analysed on a crowded two-way cycle path on which several versions of anamorphic ‘3D boxes’ were placed near the right edge. During the second study, the behaviour of 32 participants aged 50 years and above was observed while cycling a trajectory of 12 km. In both studies lateral position, SDLP (from video data), and cycling speed (from video or GPS) were measured and in the second study subjective experiences were also gathered by conducting structured interviews after the trips.

6.1. Behavioural measures

It was hypothesised that cyclists would consciously or unconsciously perceive the virtual objects and would respond to their presence by keeping more distance to them and lower their speed. Firstly, negligible and non-significant effects of the virtual objects near the edge of the cycle paths on bicyclist lateral position or SDLP were found. However, a small exploratory effect on cycling speed was found as the average speed was higher when red coloured objects were placed along the cycle path. As this variant of the objects was the only exception and the effect size was small, it remains unclear where this effect could originate from. It could be that the red colour and the white stripes made this particular object more visible than the others, which were mainly grey or black coloured. Perhaps the colour itself could have been of influence as red is often associated with danger (Pravossoudovitch, Cury, Young, & Elliot, 2014). Overall, it can be concluded that the virtual objects, in their current format, are not an effective measure to affect the course or speed of cyclists.

6.2. Looking behaviour

During both studies it was scored whether participants (clearly) looked at the virtual objects, or whether they remembered them in a structured interview after their bicycle trip in experiment 1 or 2, respectively. Data analyses revealed that cyclists who had seen the virtual objects cycled closer to the edge of the cycle path compared to the group of cyclists who had not seen the objects. In Experiment 1, this effect was very small and only marginally significant for the 2-dimensional condition only, making it unlikely that visibility was linked to 3D properties. In Experiment 2, a medium and significant decrease of lateral position as well as a medium and significant increase in SDLP were found for cyclists who had explicitly mentioned that they have seen the virtual objects. As the direction of the effect on lateral position is contrary to the a priory hypothesis, it remains unclear what the causal direction of the effects are: did bicyclists observe the objects because they were cycling closer to them, or were they cycling closer to the objects because they noticed them?

6.3. Oncoming cyclists

Although not directly related to any of the virtual objects, it was observed in the first study that many cyclists passed the experimental location while an oncoming cyclist was present. By adding this factor into the analysis, it was found that cyclists are positioned significantly closer to the edge of the cycle path when an oncoming cyclist is present compared to when no oncoming cyclist is present. This effect is also found in car driving, as drivers tend to move away from oncoming traffic, increasing their distance from the centre of the road (Triggs, 1997) even when cyclists are present in the same lane (Dozza, Schindler, Bianchi-Piccinini, & Karlsson, 2016). The medium effects in this study were found within all conditions.

6.4. Study limitations

In Experiment 2 all participants were aged 50 years or older. Therefore, these results cannot easily be generalized to other age groups. However, interventions aimed at preventing cyclists from entering the shoulder are mainly helpful for older cyclists as they are overly represented in cycling accident statistics (CBS, 2014).

Due to practical limitations it was not possible to randomly assign the experimental conditions to the participants in Experiment 2. As a within subjects design with a fixed starting point was used, it cannot be ruled out that the order of conditions exerted some effects on any of the measures. However, the fact that the virtual objects were not detected by a large proportion is an indication that order effect may not be so important.

Overall, the type of illusions used during both studies were designed rather conservative, as a 3D image of a cube along a cycle path could be considered as a non-threatening object for cyclists. This may have affected the effectiveness of the objects and their visibility. As only 22% reported that they had seen the object during Experiment 2, it could be that the design of the objects was too conservative to be influential on an overall level. Even though many participants did not see the objects, all participants were included in the analyses because the virtual objects in the periphery could affect behaviour either consciously through direct perception or unconsciously via peripheral vision. However, consciously noticing an element in the layout of a road is not an absolute requisite for it to influence behaviour as road elements can also influence behaviour without the road user having explicit knowledge (for example, see Lewis-Evans & Charlton, 2006, and Lewis-Evans, De Waard, Brookhuis, & Jolij, 2012). For this reason, discarding all participants who reported not having seeing any of the virtual objects would make it impossible to assess any unconscious or implicit effects.

Additionally, as it was observed that bicyclists regularly manoeuvre around manholes (Westerhuis & De Waard, 2016), perhaps virtual versions of these manholes could also be tested as a means of influencing the behaviour of bicyclists. Lastly, the application of these types of drawings could be limited, as it requires extra space along the cycle path which could not be used as a surface for the cycle path itself.

6.5. Implications for future research

As the optical illusions did not have an effect on cycling behaviour, perhaps other measures may be developed to fulfil this purpose. As to date there is not many research focussing on specific infrastructural modifications to influence the lateral position of cyclists, maybe existing concepts to influence car driving can be used to generate other ideas for cyclists. For example, applying different forms of delineation (e.g. Steyvers & De Waard, 2000; Godley, Triggs, & Fildes, 2000), optically narrowing the road (e.g. Wu, Hu, & Li, 2013), or providing haptic feedback upon approaching a road's edge can be used to influence the lateral position and speed of car drivers (e.g. De Waard, Jessurun, Steyvers, Raggatt, & Brookhuis, 1995). Perhaps comparable measures are also suitable to be used for cyclists as well.

6.6. Conclusion

No effects of optical illusions on lateral position choice and lateral position control were found. However, a small exploratory effect was found of the objects on cyclist speed, as the average cycling speed was higher when red coloured objects were placed along the cycle path. This effect was not found for the other conditions, however. As such, in its tested format, visual illusions were not effective. However, it was found that cyclists who were looking at the objects or reported that they have seen them were positioned more closely to the shoulder. Therefore it might be that other types of illusions, and perhaps other dimensions of illusions with increased visibility, might be noticed better and may be effective.

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